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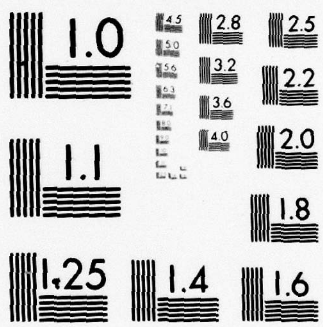

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AN EXTENSION OF ENGINE WEIGHT ESTIMATION TECHNIQUES TO COMPUTE ENGINE PRODUCTION COST

E. Onat and F. F. Tolle

Boeing Military Airplane Development
Boeing Aerospace Company
Seattle, Washington 98124

31 August 1979

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As a follow-on to previously developed engine weight estimation work, a preliminary design quality engine cost estimating code has been produced. The code relies on engine thermodynamic characteristics and weight as computed by earlier developed codes to select raw material types and quantities required to produce the engine. An existing Navy technique is then used to convert this data into engine cost. The code was used to predict the cost of three existing engines; errors ranged from 1 to 8% of actual costs as reported to NADC.

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1.0 INTRODUCTION AND SUMMARY

1.1 Introduction

The COST computer code is a preliminary design tool used to estimate the production cost and selling price of military aircraft gas turbine engines. Production cost does not include overhead and profit (which enter into engine selling price) which vary between manufacturers; if data on overhead and profit is available, the user can combine them with the COST product to estimate engine price. Often production cost estimates alone will suffice to determine the cost ranking of competing engine concepts in a preliminary design study.

COST first estimates the weight of each major component in the engine, using the method developed by the WATE-2 computer code (Ref. 1-1). The WATE-2 technique determines the weight of compressors, burners, turbines, ducts, frames, shafts, and nozzles by a preliminary design approach through consideration of thermodynamic and mechanical design variables such as: airflow, pressure ratio, maximum temperature, material density, stage loading, hub tip ratio, and shaft mechanical overspeed of each component. These variables may be determined from the thermodynamic cycle analysis of the engine or may be input by the user.

The estimated weight is transferred to cost estimating routines which are based on correlations developed by Naval Air Development Center and Naval

Air Systems Command. The correlation parameter is based on a system of classifying materials by similarity of applications in engines (Ref. 1-2). In this procedure, materials used in jet engines are placed in one of a total of six relative cost categories having to do with a combination of manufacturing cost and raw materials cost. Carbon steel and aluminum are assigned the lowest classification and used as a reference. High strength high temperature nickel cobalt alloys which are costly and difficult to machine are placed in the highest (fifth) classification. Because of differences in cost and machinability, titanium alloys are assigned a separate (sixth) classification. Two indices are developed for each material class, namely

- relative material cost
- relative machining cost.

The product of these two indices is called the "relative weighting factor".

In the cost estimation procedure, the estimated weight of each engine component is first converted to raw material weight. A raw material weight to finished material weight scaling factor, commonly referred to as "Buy/Fly" ratio, has been estimated for each component for state-of-the-art and for advanced production methods. Raw material weight is then multiplied by the relative weighting factor, and the sum of all such component products is formed. The summation for all engine components is called the "Maurer factor" in the honor of its originator, R. J. Maurer. The production cost of the engine is estimated by the linear correlation (Fig. 1-1) between engine manufacturing cost and the Maurer factor (Ref. 1-2).

The method of calculation opens the possibility of computing component costs by proportioning the component and engine Maurer factors and engine cost. However, there is little component cost data available to confirm such calculations, so component costs derived by this process could be substantially in error.

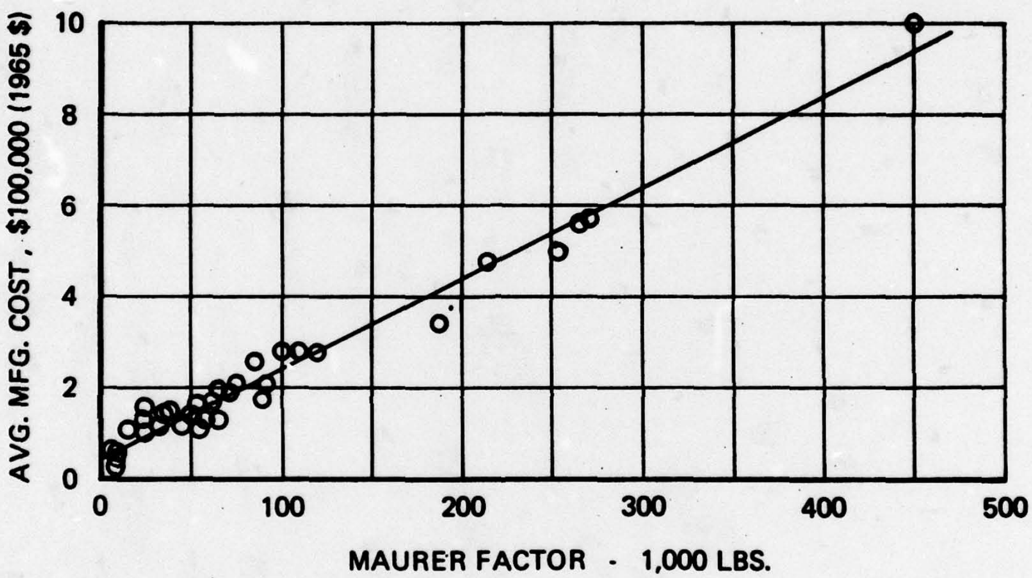

FIGURE 1-1 MAURER FACTOR CORRELATION WITH COST

1.2 Summary

A method has been developed to estimate the production cost of aircraft gas turbine engines. This method consists of a combination of a cost estimating method (Ref. 1-2 and 1-3) developed by Naval Air Development Center and Naval Air Systems Command and WATE-2 (Weight Analysis of Turbine Engines, Ref. 1-1) developed by The Boeing Company. This method is incorporated into a new computer code called COST.

COST determines the finished weight of each major component in the engine, and multiplies it by a factor which varies with production methods to produce an estimate of the raw material weight. Estimated component raw material weight is then multiplied by "relative material cost" and "relative machining cost" factors; these products are next summed over all components to arrive at the "Maurer factor", (Ref. 1-2, 1-3). Finally, the Maurer factor is transferred into a cost estimating routine developed by Naval Air Development Center where the production cost of the engine is calculated.

2.0 MATERIALS USAGE

Reports from Naval Air Development Center (Ref. 1-3), Battelle Columbus Laboratories (Ref. 2-1) and Boeing Propulsion Data Files were the principle sources used to determine materials used in major components of a jet engine. During the course of analysis, it became apparent that two classifications were required: one dealing with present state of the art materials, and the other with materials expected to be available for use in 1985 and subsequent years. The advanced materials list was arrived at by discussions with Navy, NASA, Army, and Air Force Material Development Program Managers and by the use of the NASA-MATE (Materials for Advanced Turbine Engines program) Program Reviews. A review of ASTM materials which find use in turbine engines was conducted. For those materials included in the COST program, the output format can be made to list the material generic name and, where assigned, the ASTM number.

2.1 Current Technology Material Classification

Figure 2-1 presents the material classification for current technology materials and is extracted from References 1-2 and 1-3. A separate advanced materials classification presented later includes materials such as those produced by powder metallurgy which are not widely used in current aircraft engines. Actual material selection for a specific engine depends on design factors such as temperature, cooling, or proprietary considerations which are refinements not possible in a preliminary design tool. Accordingly no specific materials are singled out within a particular material class.

	MAJOR MATERIAL CLASSES					
	CONV	A	B	C	D	TI
RELATIVE MATERIAL COST	1.0	3-4	4-5	5-7	7-10	7
RELATIVE MACHINING COST	1.0	1.9	3.1	4.0	3.5	1.5
MAURER FACTOR		6,7	14.0	24.0	29.8	10.5
TYPICAL MATERIALS	CARBON STEEL 321SS ALUMINUM	A256 17-4PH GREEK ASCOLOY	HASTELLOY–X HASTELLOY–B INCO-706	INCO–713 INCO–625 L–605	WASPALOY RENE' 41 ASTROLOY	6AL–4V 6AL–6V–25 TI 17

Figure 2-1 Material Classes for Current Technology Engines

2.1.1 Fans and Compressors

The engine component weight estimator selects either titanium or steel, depending on stage inlet temperature, and adjusts material density accordingly. This capability is necessary to estimate the weight of a high pressure compressor where the high temperatures in the later stages make it necessary to use steel alloys. The default changeover temperature limit from titanium to steel is 700°F (371°C). Some of the compressor materials are presented below.

Class Ti (Titanium Alloys) - These alloys are used in stages where the inlet temperature is below the maximum allowable temperature for titanium.

Ti-6AL-4V

Ti-8AL-1MO-1V

Ti-679

Ti-6-2-4-R

Class A (Superalloys) - These alloys are used in stages where the inlet temperature exceeds the allowable temperature for titanium alloys.

Greek Ascoloy

Incoloy-901

Inconel-718

Waspaloy

Inconel-X-750

2.1.2 Combustor (Class B)

The alloys used for combustors and their liners, and for the transition ducts connecting the combustors to the turbine inlet nozzles are formable, weldable sheet alloys. They are capable of 8,000 to 10,000 hours of operation in an oxidizing environment at average material temperatures of 1650°F or more. The alloys must be stable for this long time, high temperature service and must have excellent thermal

fatigue and distortion resistance. Some of the alloys used in combustors are

Hastelloy-X

Hastelloy-B

Inconel-600

AISI-310

AISI-321

AISI-347

2.1.3 Turbine (Class D)

The turbine section of the gas turbine engine is one of the most demanding in terms of material properties because of the combination of temperatures and stresses. These materials are either nickel base alloys or carbide strengthened cobalt base alloys for applications up to 2000°F, and dispersion strengthened materials above 2000°F. Some of these materials are:

Rene-41

Astroloy

Diskoloy

Inconel-718

Udimet-500

2.1.4 Shafts (Class A or Class C)

Shafts transmit the torque from the turbines to the compressor sections of the engine. Therefore they must have high fatigue and high yield strength properties. Depending on operating temperature, torque and length, shafts are made of low alloy steels, CR-MO-V steels and occasionally nickel base alloys. Turbine shafts require a combination of

properties that is difficult to get in a single material. High yield and fatigue strength are needed at the cold end, and high yield and creep strength plus oxidation resistance are needed at the hot end. Materials which afford a reasonable compromise are

17-22A

Inconel 718

Waspaloy

A-286

2.1.5 Ducts and Nozzles (Class Ti or Class B)

Titanium, nickel base, and cobalt base alloys are choices for use in ducts and nozzles depending on temperature. Some of these materials are:

Ti-6AL-4V

Inconel-600

AISI-321

AISI-347

Nimonic-75

2.2 Advanced Technology Material Classification

Research programs are being conducted by both industry and government for the purpose of developing alloys with improved hot strength, better micro-structural stability after long time exposure to high temperature, and improved resistance to corrosive and erosive attack by combustion products. From a cost reduction standpoint, new manufacturing methods to improve material properties and to decrease scrap material loss are of

great importance. Powder metallurgy, as an example, offers some important potential advantages over conventional castings:

- o reduces labor and material cost because powder metallurgy parts are closer to finished size
- o produces shapes with a high degree of reproducibility
- o permits blending of otherwise incompatible materials to produce a chemically homogeneous structure with uniform mechanical properties
- o eliminates some processing steps such as forging
- o allows improved grain size and grain growth control by techniques such as the hot isostatic process (HIP)

Powder technology is relatively new and little information on manufacturing costs and material costs are available. In the absence of definitive data, the COST code uses the same relative material cost and relative machining cost for advanced technology materials as are used for conventional materials (Figure 2-1). However, the default buy/fly ratio for powder technology is 2, reflecting near net shape production possibilities. When relative material cost and relative machining cost for any of the advanced materials become known, these values can be inserted into the code using the user input mode.

2.2.1 Fans and Compressors (Class Ti)

Titanium alloy/powder metallurgy compressor blades, vanes, and disks are under research. Some of the advanced alloys under consideration are:

Ti-6AL-6V-2SN

Ti-6-2-1.5-1BISI

Ti-6-2-2-2-2-SI

Ti-6AL-2SN-42R-2MO

2.2.2 Turbines (Class D)

Superalloy powders that are shaped into turbine disks by hot isostatic process, where the powder is compressed under high temperature and vacuum conditions, show great potential in cost savings.

The controlled solidification process includes directional solidification of conventional alloys and single crystal growth techniques. These processes will contribute significantly to improved blade life by eliminating intercrystalline cracking, one of the common blade failure mechanisms.

Directional solidification of "eutectic" alloys is another area of active research, and shows promise of turbine blade materials in which turbine inlet temperatures can be increased about 100° to $150^{\circ}F$ as compared to conventional nickel base superalloys. Some of the turbine advanced materials under research are:

AF2-1DA
WA2-20
TA2-8B
LDA-204

2.2.3 Combustors (Class B)

Some of the advanced materials under consideration for combustors are:

Hastelloy-S
Hastelloy-T
Inconel-617
TD-NiCrAlY

2.2.4 Other High Temperature Materials

Intermetallic alloys, refractory metal alloys and ceramics have potential use in jet engines, but these materials and processes are not included in the present COST code, because of limited data on cost and use.

2.3 COST Computer Code

The computer model follows the same material classification presented in References 1-2 and 1-3. Figure 2-1 presents the original group of materials used and their corresponding relative machining cost and relative material cost factors. Additional state-of-the-art materials have been added to the referenced lists; the array incorporated into the computer program, in addition to the original group, is shown in Figure 2-2.

MAJOR MATERIAL CLASSES				
A	B	C	D	Ti
AM -355	AISI 310	AISI 4140	IN - 100	Ti - 8AL - 1MO -IV
INCO - 901	AISI 347	AISI 4340	H53V	Ti - 679
RENE - 95	IN 586	NITRALLOY 135	TIMKIN 16 -25 -6	Ti - 6 - 2 - 4 - 8
AISI410	TD NiCRAIY	C455	MAR - M432	Ti - 17

Figure 2-2 Additional State-of-the-Art Material by Class

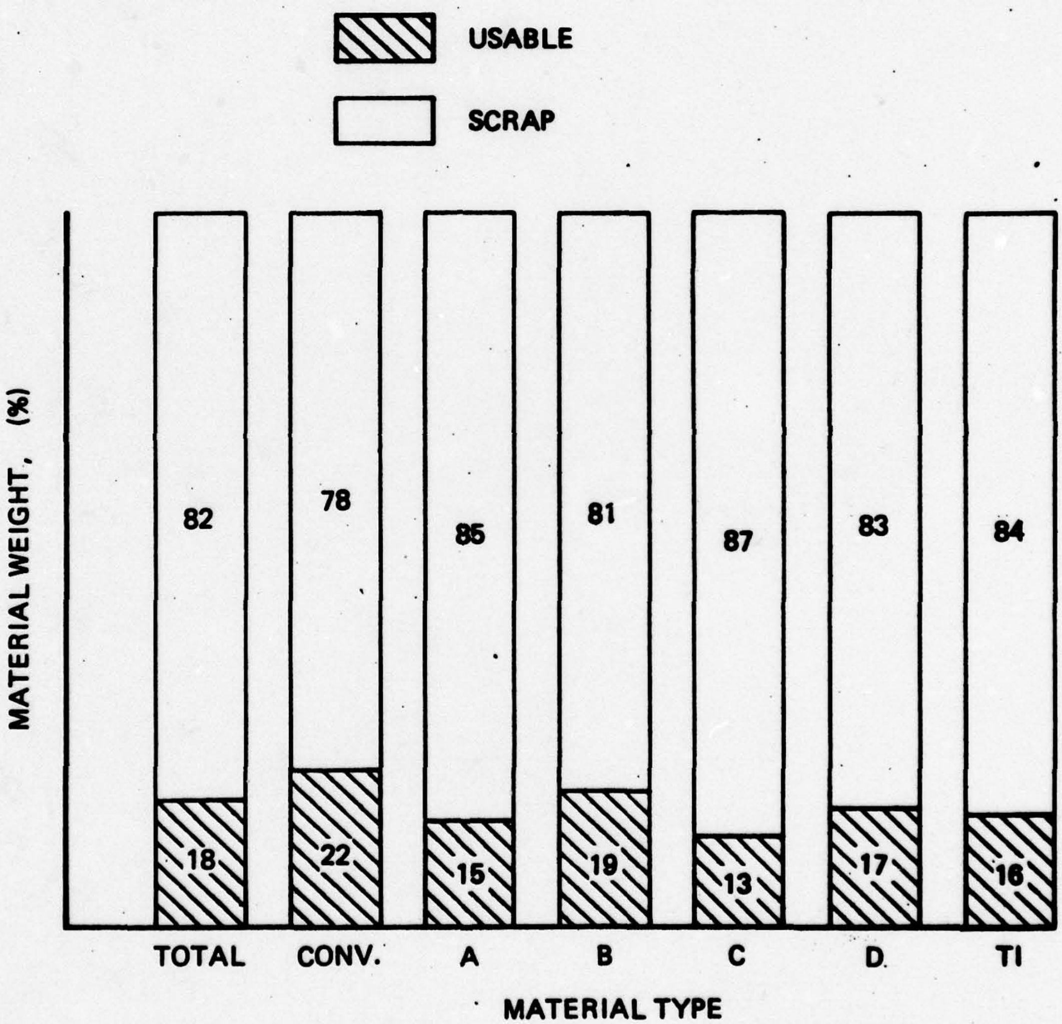

Figure 2-3 Manufacturing Efficiency

Raw material weight to finished part weight ratio is referred to as the buy/fly ratio in the computer model. Buy/fly ratios for different classes of materials were estimated from data obtained from industry and References 1-3 and 2-4. A summary of manufacturing efficiency (buy/fly data) for the selected material classes drawn from these references is presented in Figure 2-3. After several simulations of engines in the Boeing data base, these buy/fly ratios were felt to be overly pessimistic, and hence were modified. A more representative state-of-the-art buy/fly value for machined castings and forgings is 4 while for sheet material it is 2. When the advanced technology mode is used, the powder manufacturing method buy/fly ratio is 2. These buy/fly values can be modified by the user as more experience is gained with the model or new processes are developed; in the interim, COST default buy/fly values have been set as indicated.

The user has the option to override all the defaulted variables that affect the Maurer factor for the component or the total engine under study. These variables are buy/fly ratio, relative material cost, and relative machining cost.

The COST output presents material class, buy/fly ratio, raw material weight, relative machining cost, relative material cost, a "component" Maurer factor, and an engine aggregate Maurer factor. A sample output for a primary burner is presented in Figure 2-4. Material lists by class can be output as a user option (Figure 2-5).

```
*************
*           *
*  PBUR  8  *
*           *
************2

MAX CONDITIONS OCCUR AT
*****************************************
        ALT        MN         VALUE
PTOT     0.      0.000      274.8 LB/SQIN
TTOT     0.      0.000     1392.1 DEG R
CWIN     0.      0.000       12.0 LB/SEC
*****************************************
BURNER NUMBER     2
  RIN     ROUT     LENGTH     MACH     WSPEC
  0.000    9.588    30.720     .071     5.968
  CAS WT  LIN WT   NOZ WT    INC WT    FRAME    WTOT
    17.6    30.5     29.9       0.0     83.5   161.6


          ESTIMATED COMPONENT COST SUMMARY
             CURRENT TECHNOLOGY
          *******************************
BURN
********


            CASE  LINING              NOZZLE
MATERIAL          GROUP B             GROUP B
MANF.METH         SHEET               FORG
FINISHED WT        48.                 30.
BUY/FLY           2.00                4.00
RAW MTL WT         96.                120.
MTL COST F        4.50                4.50
MAN COST F        3.10                3.10
MAURER   F        1344.                1671.

FRAME  1
********
MATERIAL          GROUP A
MANF.METH         FORG
FINISHED WT        83.
BUY/FLY           4.00
RAW MTL WT         334.
MTL COST F        3.50
MAN COST F        1.90
MAURER   F        2221.

TOTAL MAURER FACTOR FOR THIS COMPONENT IS    5235.
******************************************************

CUMULATIVE MAURER FACTOR                         51679.
******************************************************
```


Figure 2-4 Primary Burner Output

MATERIAL CLASSIFICATION
****

GROUP T
****

6AL4V	AMS4965
6AL6V	AMS4971
8AL1MO	AMS4973

GROUP A
****

A-286 GA	AMS5525
17-4PHSS	AMS5639
AM-350	AMS5542

GROUP B
****

INCO-625	AMS5599
HASTEL-X	AMS5754
HASTEL-B	AMS5755

GROUP C
****

L-605	AMS5537
INCO-718	AMS5382
INCO-625	AMS5599

GROUP D
****

WASPOLOY	AMS5704
RENE-41	AMS5712
DISKOLOY	AMS5731

GROUP ADV
****

TI-6AL-6V-2SN	COMPRESSOR ALLOY
TI-6-2-1.5-1BISI	COMPRESSOR ALLOY
TI-6-2-2-2-2-SI	COMPRESSOR ALLOY
TI-6AL-2SN-42R-2MO	COMPRESSOR ALLOY
WAZ 20	BLADE ALLOY
AF2-1DA	TURBINE DISKS
TAZ8B	BLADE ALLOY
LDA 204	CAST BLADES
INCONEL 617	COMBUSTOR
TD-NIRALY	COMBUSTOR
MAR-M905	1400 F SHEET
UNITEMP 300	1200 F ALLOY
PA101	POWDER ALLOY
IN-853MA753	POWDER ALLOY
HASTELLOY S	CYCLIC HEAT
HASTELLOY T	LOW EXPANSION

Figure 2-5 Material Classification Output

2.4 Program Validation

A contractually required verification of the accuracy of the newly developed portion of the code was done by applying it to three engines and comparing the results with Maurer factors furnished by NADC. Results of the COST program estimates for these engines are shown in Figure 2-6. As can be seen, Maurer factors for the three selected engines are within the ±10% accuracy goal for the program.

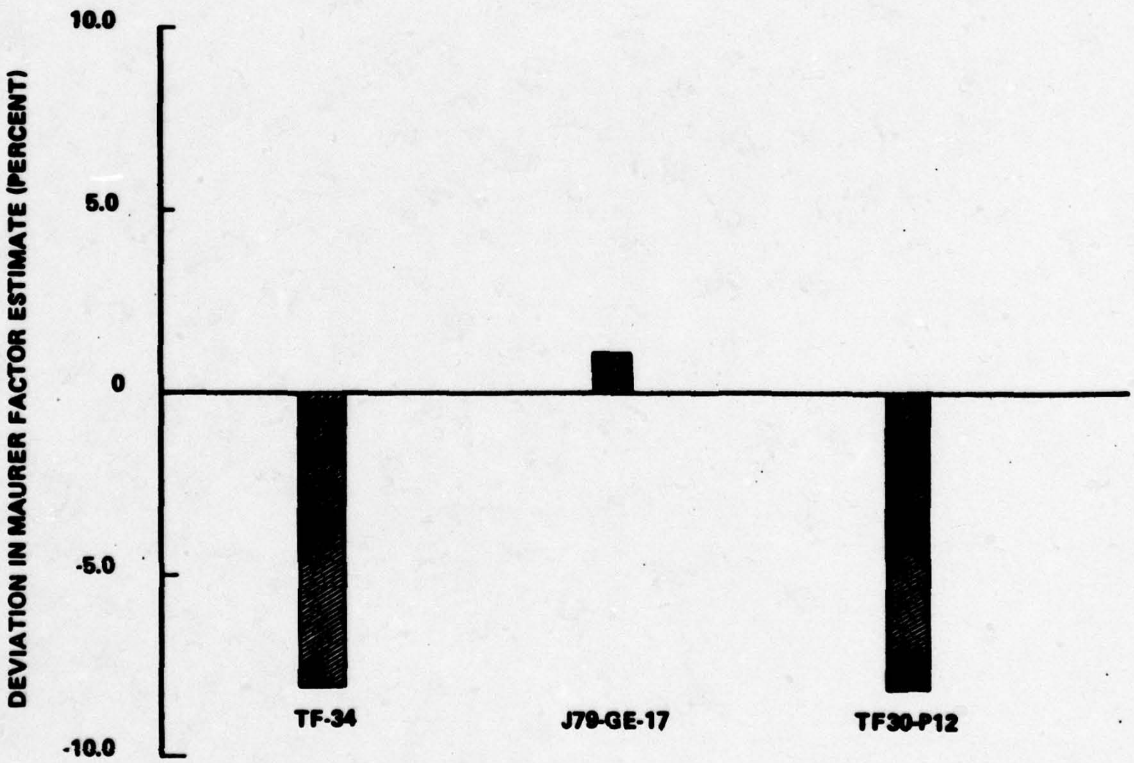

Figure 2-6. Program Results in Estimating Maurer Factor

3.0 USER'S MANUAL

This section contains a description of input-output data, values of typical inputs, and a sample case. COST has been incorporated into two versions of the earlier weight codes -- the engine component analysis "Navy Stand Alone" program and the "NASA-Navy Engine Program" (Ref. 3-1).

The overall program structures modified to incorporate cost estimation are shown in the flow charts presented in the sections for the two different programs. The COST/Navy Stand Alone code will be referred to as the NAVY/COST code, and the NASA-Lewis code will be referred to as NASA/COST.

3.1 "Navy Code" Program Structure

The overall program structure and connectivity to the earlier engine component analysis code (WTINTR) are shown in Figures 3-1 and 3-2.

ENGINE COMPONENT ANALYSIS

WEIGHT

MAURER
FACTOR
&
COST DATA

FIGURE 3-1 OVERALL "NAVY CODE" PROGRAM STRUCTURE

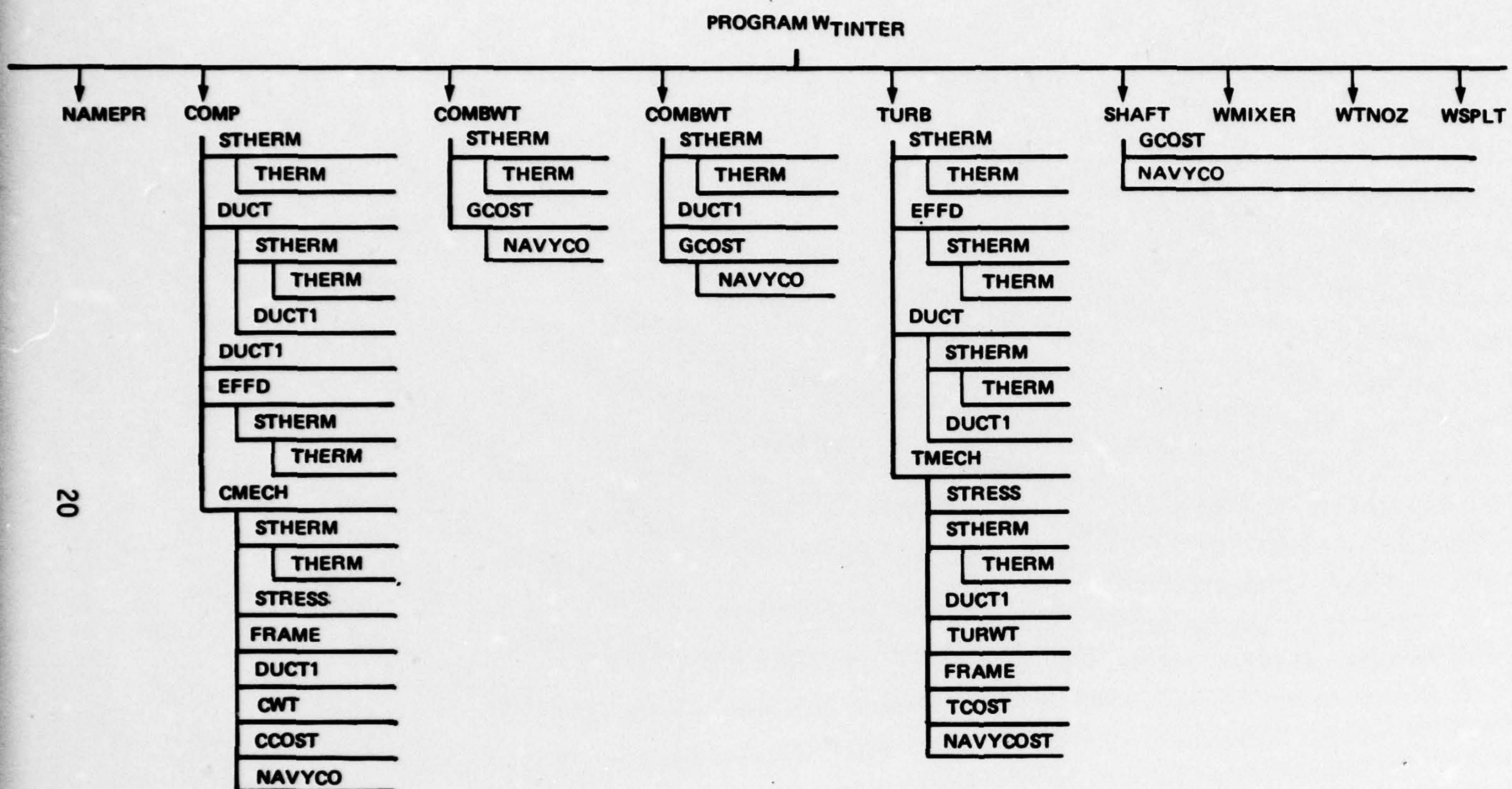

Figure 3-2 Diagram of Subroutine Connectivity

3.1.1 Input Description and Format

For users of this version of the cost code, reference must be made to the NADC Engine Performance Group for input format and methods of running the engine component analysis code (WTINTR). The following comments describe inputs to WTINTR which are required to run NAVY/COST.

3.1.2 Mode Indicators

- MODE = 0 Do not do MAURER factor calculation
  - = 1 Current technology default values
  - = 2 Advanced technology default values
  - = 3 User technology utilizing user inputs
  - = 4 Current technology default values and list current and advanced materials by material classification

- MODE 1 = 0 Long output
  - = 1 Short output - component MAURER factor and cumulative MAURER factor

- MODE 2 = 0 Do not execute Navy cost routine
  - = 1 Execute Navy cost routine

3.1.3 User Technology Inputs

The user has the option to input certain of the following variables depending on the component that is being simulated.

BFR	=	Buy/Fly ratio
MTLF	=	Material cost factor
MANF	=	Manufacturing cost factor
HDBFR	=	Buy/Fly ratio for fan, compressor and turbine stages that require different material because of high temperature
HDMTLF	=	Material cost factor for fan, compressor and turbine stages that require different material because of high temperature
HDMANF	=	Manufacturing cost factor for fan, compressor and turbine stages that require different material because of high temperature

3.1.3.1 Fan or Compressor

The user selectable variables are listed for the major items in the low temperature rotating elements of the engine.

Blades and Vanes

BFR, MTLF, MANF, HDBFR, HDMTLF, HDMANF

Disks

BFR, MTLF, MANF, HDBFR, HDMTLF, HDMANF

Case

BFR, MTLF, MANF

Miscellaneous

BFR, MTLF, MANF

3.1.3.2 Turbine

The user selectable variables for the turbines of the engine are:

Blades and Vanes

BFR, MTLF, MANF, HDBFR, HDMTLF, HDMANF

Disks

BFR, MTLF, MANF, HDBFR, HDMTLF, HDMANF

Case

BFR, MTLF, MANF

Miscellaneous

BFR, MTLF, MANF

3.1.3.3 Burner

The user selectable variables for the combustor and high turbine nozzle are:

Case and Linings

BFR, MTLF, MANF

3.1.3.4 Nozzle and Thrust Reverser

The user selectable variables for the engine nozzle components are:

BFR, MTLF, MANF

3.1.3.5 Ducts

The user selectable variables for the various engine ducts are:

BFR, MTLF, MANF

3.1.3.6 Air Inverting Valve (AIV), Mixer, Heat Exchanger

The user selectable variables for these special purpose engine elements are:

BFR, MTLF, MANF

3.1.4 Navy Cost Subroutine Inputs

Entries and typical values are presented in the following arrays.

Enter

A, B, CURVE, OHDI, PROFIT

VARIABLE	DESCRIPTION	TYPICAL VALUE
A	Slope of MAURER curve	1.875
B	Intercept of MAURER factor curve	48296
CURVE	Learning curve	0.90
OHDI	Manufacturers overhead rate	.12
PROFIT	Manufacturers profit	.10

NYR1, NYR2

Beginning and end of production ie 1, 10 means 10 years of production

Q(1), Q(2), Etc.

Quantity produced each production year; i.e., 100, 100 means 100 units during first and second production year.

3.2 NASA/COST Program Structure

The overall program structure and connectivity are shown in the Figures 3-3 and 3-4. In order to execute the program, it is first necessary to run NNEP to generate thermodynamic data and subsequently enter WATE II inputs as described in Reference 1-1, and to additionally enter COST inputs as described below.

3.2.1 Input Description and Format

The COST inputs are free-field format (NAMELIST), and begin in column 2. There is no specified order to the inputs. Figure 3-5 shows the WATE2/COST input set for a typical case.

3.2.2 Mode Indicators

- o MODEC = 0 Do not calculate MAURER FACTOR
  - = 1 Current technology default values
  - = 2 Advanced technology default values
  - = 3 User technology utilizing user inputs
  - = 4 Current technology default values and material classification list

- o MODEC1 = 0 Long output
  - = 1 Short output-component MAURER factor and cumulative MAURER factor

- o ICOST = 0 Do not execute Navy cost routine
  - = 1 Execute Navy cost routine

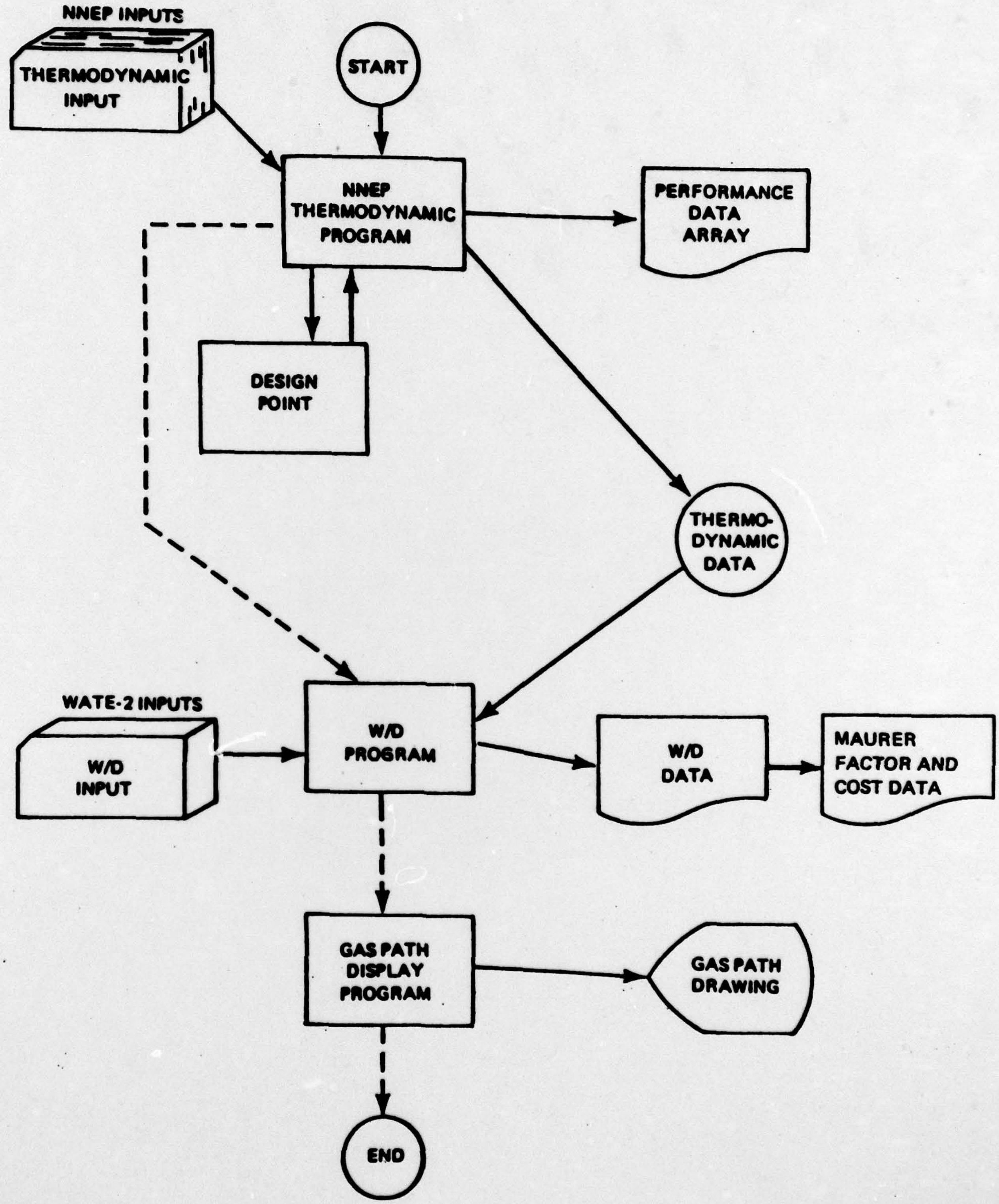

Figure 3-3 NASA/COST Overall Program Structure

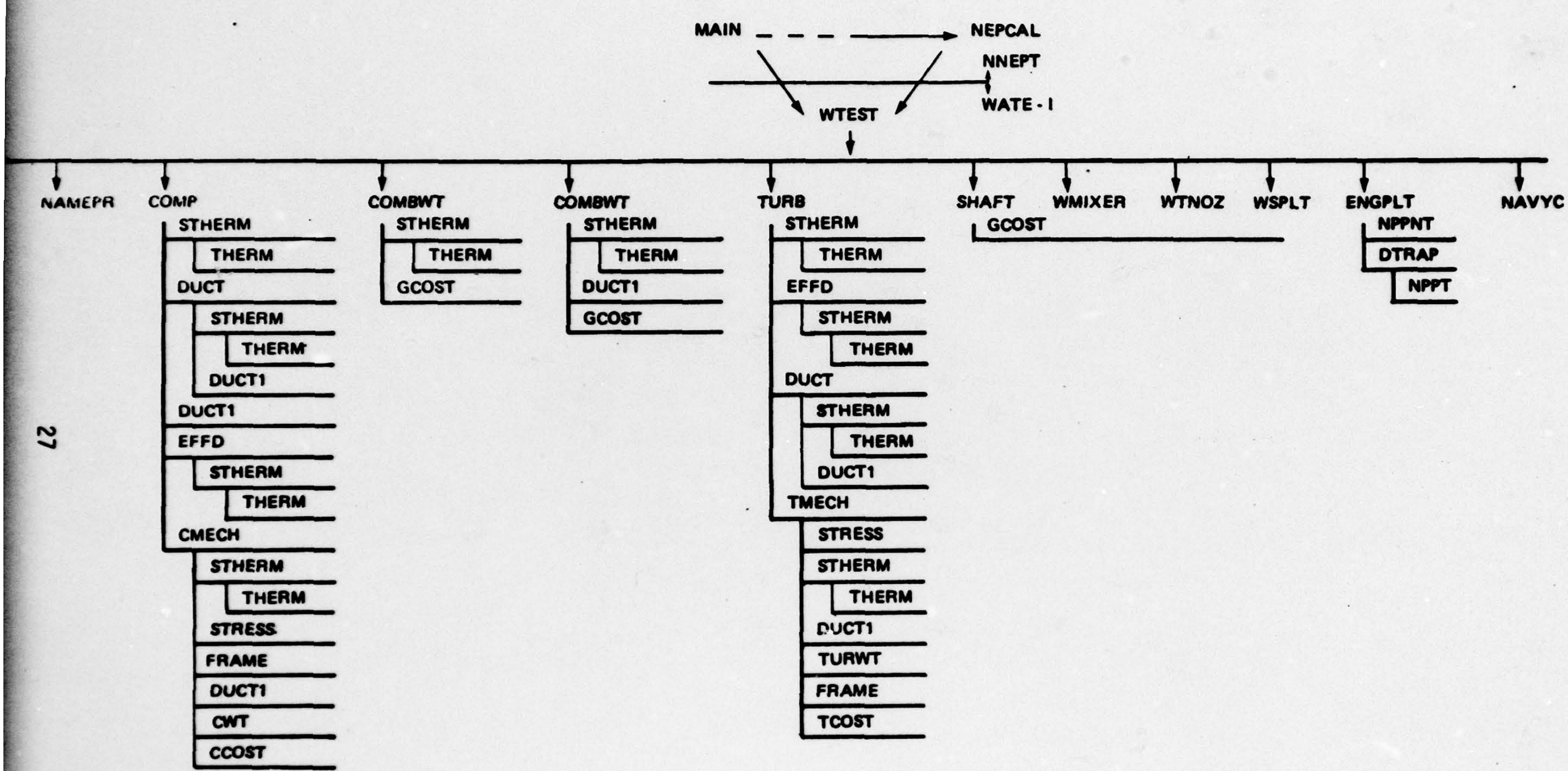

Figure 3-4 Diagram of Subroutin Connectivity

```
$W
IWT=2,IPLT=T,
ISII=F,ISID=F,IOUTCO=2,
ILENG(1)=2,3,4,5,6,7,8,9,10,11,12,
DISKWI=0.,
ACCS=.001,
MODEC=4,
ICOST=1,
ICOST1(1)=1,10,
IWMEC(1,2)=11113 ,0,1,1,3*0,
IWMEC(1,3)=99999,6*0,
IWMEC(1,4)=55551,2,5*0,
IWMEC(1,5)=11111 ,1,3*0,15,0,
IWMEC(1,6)=55551,2,5*0,
IWMEC(1,7)=11112 ,1,5*0,
IWMEC(1,8)=22221,1,5*0,
IWMEC(1,9) =33331 ,1,7,0,0,4*0,
IWMEC(1,10)=55551,2,5*0,
IWMEC(1,11)=33332 ,1,2,0,0,2*0,
IWMEC(1,12)=55551,1,5*0,
IWMEC(1,13)=22222,0,5*0,
IWMEC(1,14)=88888 ,1,5*0,
IWMEC(1,15)=66661,1,11,3*0,5,
IWMEC(1,16)=66661,2,9 ,3*0,7,
DESVAL(1,2)=.40,1.4,.32,1.,5.5,5.5,.45,0.,0.,1.,0.,2.,1.544,4*0.,
DESVAL(1,3)=15*0.,2*0.,
DESVAL(1,4)=.5,20.,0.,4.,10*0.,4.2,2*0.,
DESVAL(1,5)=.50,1.28,.32,1.5,1.8,1.5,.45,0.,0.,1.,0.,2.,1.,4*0.,
DESVAL(1,6)=.45,5.5,0.,5.,11*0.,2*0.,
DESVAL(1,7)=.5,1.20,.65,2.5,1.15,1.15,.3,0.,0.,1.,0.,2.,.73,4*0.,
DESVAL(1,8)=129.,.0200,15*0.,
DESVAL(1,9) =.23,.29,1.2,1.1,1.1,.4,150000.,1.,1.,12.,7*0.,
DESVAL(1,10)=.5,3.5,0.,-1.,11*0.,2*0.,
DESVAL(1,11)=.50,.3,1.05,1.58,1.58,.4,150000.,3.,1.,12.5,7*0.,
DESVAL(1,12)=.6,.5,0.,14.,11*0.,2*0.,
DESVAL(1,13)=280.,.0274,15*0.,
DESVAL(1,14)=.8,13*0.,0.,2*0.,
DESVAL(1,15)=50000.,.3,.85,12*0.,2*0.,
DESVAL(1,16)=50000.,.3,13*0.,2*0.,
DECOST(1,1)=0.,1.,1.,4.,1.,1.,
DECOST(1,2)=4.,1.,1.,4.,1.,1.,
DECOST(1,3)=2.,1.,1.,
DECOST(1,4)=4.,1.,1.,
DECOST(1,5)=0.,2.,2.,4.,2.,2.,
DECOST(1,6)=4.,2.,2.,4.,2.,2.,
DECOST(1,7)=2.,2.,2.,
DECOST(1,8)=4.,2.,2.,
DECOST(1,9)=0.,
DECOST(1,11)=0.,
DECOST(1,13)=0.,
DECOST(1,14)=0.,
DCOST1(1)=1.875,48296.,0.95,1.25,0.1,5*0.,
DCOST(1)=50.,50.,200.,200.,200.,200.,200.,200.,100.,100.,
$END
```

Figure 3-5 User Input

3.2.3 User Technology Inputs

DECOST (6, 18) is a NAMELIST array. The input variables are defined as

VARIABLE	DESCRIPTION
BFR	Buy/Fly ratio
MTLF	Material cost factor
MANF	Manufacturing cost factor
HDBFR	Buy/Fly ratio for fan, compressor and turbine stages that require different material because of high temperature
HDMTLF	Material cost factor for fan, compressor and turbine stages that require different material because of high temperature
HDMANF	Manufacturing cost factor for fan, compressor and turbine stage that require different material because of high temperature

3.2.3.1 Fan and Compressor

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,1) - (6,1)	Blade and Vane	BFR, MTLF, MANF, HDBFR, HDMTLF, HDMANF
(1,2) - (6,2)	Disk	
(1,3) - (3,3)	Case	BFR, MTLF, MANF
(1,4) - (3,4)	Misc	

3.2.3.2 Turbine

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,5) - (6,5)	Blade and Nozzle	BFR, MTLF, MANF, HDBFR, HDMTLF, HDMANF
(1,6) - (6,6)	Disk	
(1,7) - (3,7)	Case	BFR, MTLF, MANF
(1,8) - (3,8)	Misc	

3.2.3.3 Burner

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,9) - (3,9)	Case and Lining	BFR, MTLF, MANF
(1,10) - (3,10)	Nozzle	

3.2.3.4 Nozzle and Thrust Reverser

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,11) - (3,11)	Nozzle	BFR, MTLF, MANF
(4,11) - (6,11)	High Temp Nozzle	
(1,12) - (3,12)	Thrust Reverser	BFR, MTLF, MANF
(4,12) - (6,12)	High Temp Thrust Reverser	

3.2.3.5 Shaft

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,13) - (3,13)	Shaft	BFR, MTLF, MANF

3.2.3.6 Duct

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,14) - (3,14)	Duct	BFR, MTLF, MANF
(4,14) - (6, 14)	High Temp Duct	BFR, MTLF, MANF

3.2.3.7 AIV, MIXER, Heat Exchanger

ARRAY LOCATION	DESCRIPTION	VARIABLE
(1,15) - (3,15)	AIV, MIXER or Heat Exchanger	BFR, MTLF, MANF

Array locations (1,16) through (6,16) are for future use.

3.2.4 Navy Cost Subroutine Inputs

o ICOST1(2) is a NAMELIST Array

ICOST1(1) and ICOST1(2) are total production time indicators

Example Total production time = 10 years

ICOST1(1) = 1,10

- DECOSTI(10) is a NAMELIST Array

  DECOSTI(1) = Slope of MAURER factor curve (1.875 TYP)

  DECOSTI(2) = Intercept of MAURER factor curve (48296 TYP)

  DECOSTI(3) = Learning curve (.90 TYP)

  DECOSTI(4) = Manufacturers overhead rate (.12 TYP)

  DECOSTI(5) = Manufacturers profit (.10 TYP)

  DECOSTI(6)-(10) = For future use

- DECOST(20) is a NAMELIST Array

  DECOST(1) through DECOST(20) = Yearly production rates.

REFERENCES

1-1 Onat, E. and Klees, G. W., "A Method to Estimate Weights and Dimensions of Large and Small Gas Turbine Engines", CR159481, January 1979.

1-2 Brennan, T. J., and Taylor, R. N., Steinert, A. G., "Cost Estimating Techniques for Advanced Technology Engines", SAE 700271, April 1970.

1-3 Brennan, T. J. and Finizie, L T., "Gas Turbine Engine Cost Estimating", AIAA Paper No. 76-752, July 1976.

2-1 Simmons, W. F., "Current and Future Materials Usage in Aircraft Gas Turbine Engines", AD-766334, June 1973.

3-1 Fishbach, L. H., and Caddy, M. J., "NNEP-The NAVY NASA Engine Program", NASA TM X-71857, December 1975.